




Memo

date: Oct. 4, 2013
to: RSC; A. Rusek and C. Pearson
from: D. Beavis 
subject: Chipmunk on NSRL Berm Top and Maximum Exposure at the Fence

Motivation and Recommendation

The NSRL facility has a chipmunk, NMO130, on top of the berm. The berm is posted as a controlled area with access administered through OPM 4.46.

The chipmunk on the berm failed 1-2 years ago causing some loss in operating time while the device was replaced. The berm does not have stairs or other means of convenient access to service the chipmunk. Access can be difficult in the winter and when the grass is high in the summer. The area is potentially infested with ticks and chiggers during the warmer months. It was requested that the need for this chipmunk be re-examined in an effort to reduce the risk of lost operating time and possible injury to personnel who service the chipmunk.

**The final recommendation to the RSC is to approve removal of the berm chipmunk.
The RSC may want to consider other controls.**

History and Layout

The NSRL beam line layout is shown in Figure 1 and Figure 2. There are two entrance labyrinths into the facility. Each of these labyrinths house chipmunks to monitor for beam faults and reduce dose outside the fences and tunnel perimeter. A cross-sectional view of the tunnel is shown in Figure 3.

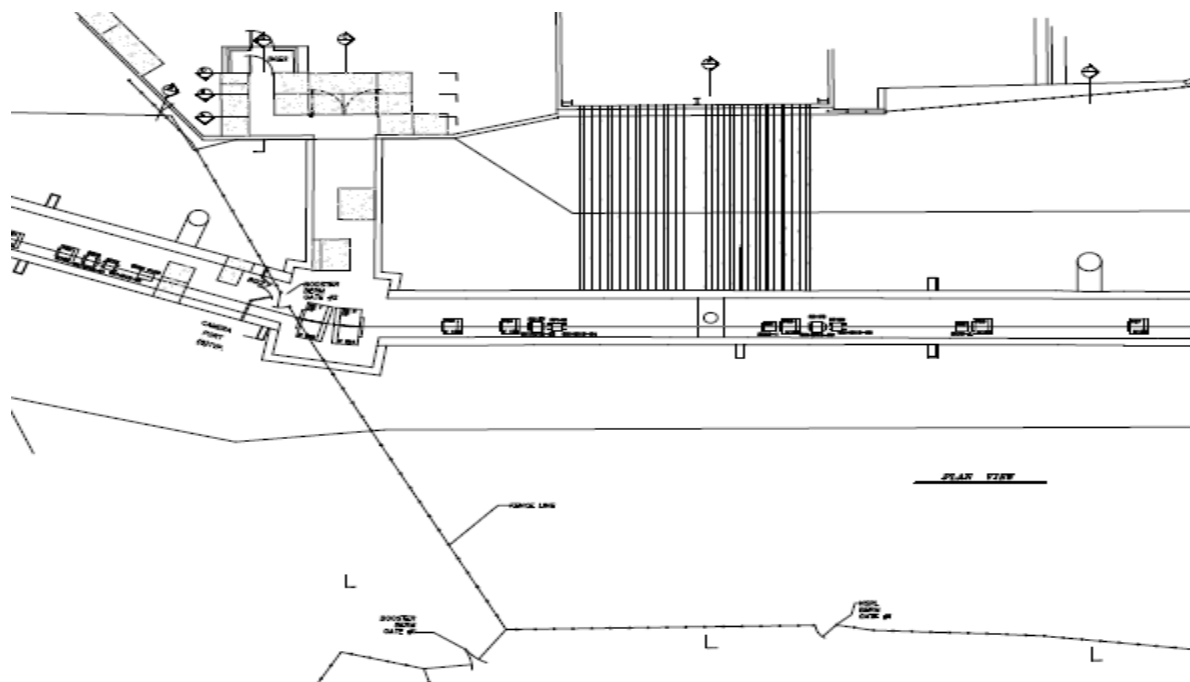


Figure 1: Upstream portion of the NSRL beam line. The upstream labyrinth, the power supply building and the fence line are shown.

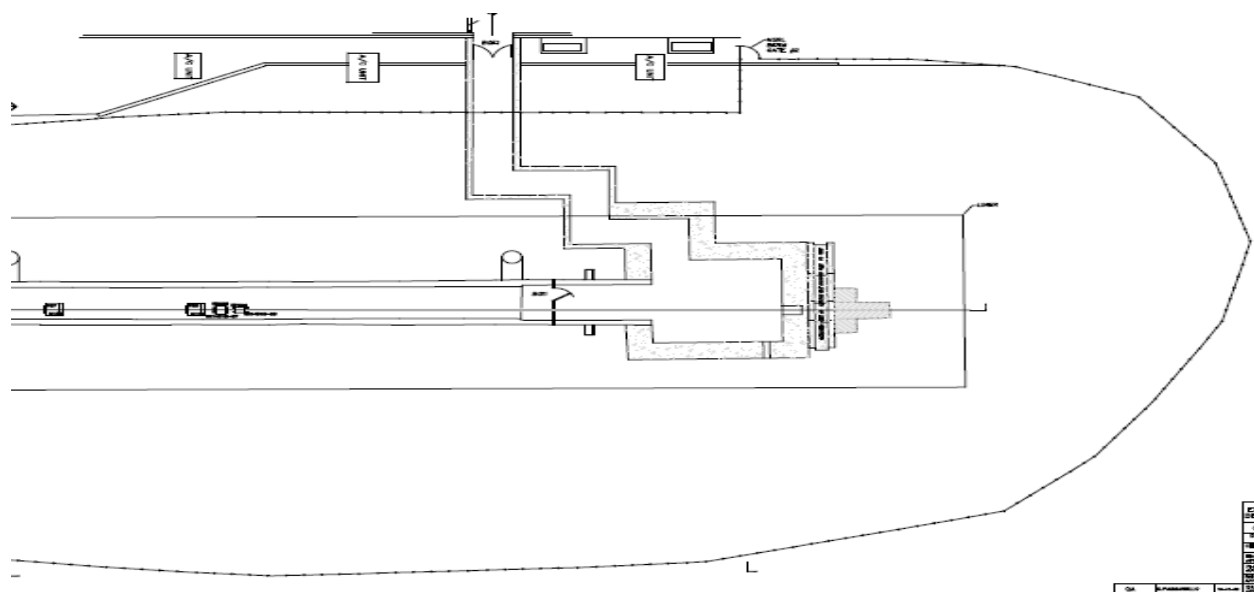


Figure 2: The downstream portion of the NSRL beam line showing the users building, the downstream labyrinth and the perimeter fence.

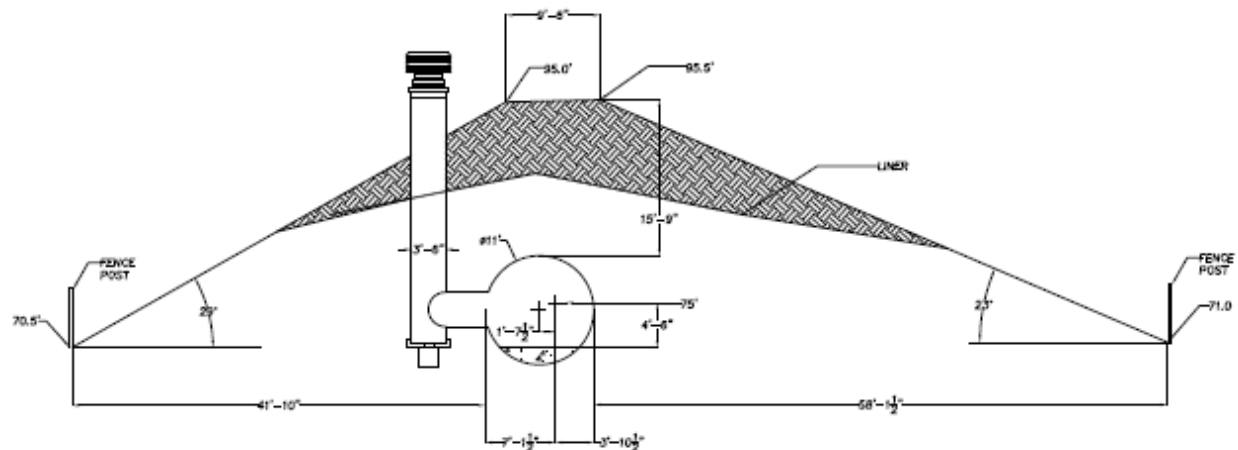


Figure 3: Cross sectional view of the NSRL earthen shield.

There are a total of three chipmunks at the NSRL facility. Radiation monitors NMO130, NMON131, and MNON132 are interlocking and intended to mitigate potential dose during beam faults in the NSRL beam line. There are several other monitors in the upstream stub tunnel that are used to mitigate dose during Booster faults. The two chipmunks NMO131 (target room labyrinth) and NMO132 (upstream labyrinth) monitor and protect the areas near the labyrinths. A fault study¹ with 2 GeV protons was conducted and the interlock sensitivity was established for several fault locations along the beam transport. The fault studies verified that the labyrinth chipmunks provide protection for the labyrinth areas and also for areas outside the berm near the labyrinth. NMO130 was originally located over the top of the target area. The fault studies identified that there may be a portion of the transport line where large beam faults could occur and NMO131 and NMO132 would not sufficient sensitivity to mitigate the dose at the fence. This area was between the power supply house and before the target area. NMO130 was moved upstream on the berm to provide sensitivity to such beam faults and limit the dose at the fence. The dose estimates at that time only accounted for solid angle and did not take into account the angular dependence of the radiation from the berm. This method provides a conservative estimate of the dose at the fence. A more detailed treatment will be discussed in the next section.

The area near most of the fence around the NSRL berm is an uncontrolled area. The C-AD shielding policy requires that no more than 20 mrem can be received in a beam fault for uncontrolled areas. NMO 130 monitors the dose external to the shielding and prevents that from happening. The next section will demonstrate that the dose rate at the fence is sufficiently low that administrative means should be sufficient to prevent more than 20 mrem at the fence line from an unlikely high intensity beam fault. The dose outside the shielding and along the fence line is monitored by environmental TLDs, which can be used to estimate the dose from an accident.

¹ A Rusek, NSRL Fault Studies, May 26, 2004; <http://www.c-ad.bnl.gov/esfd/RSC/Memos/NSRL%20Fault%20Studies.pdf>

The maximum possible beam faults in NSRL occur if either NSRL is operating at its ASE limits or if the Booster is operating at its ASE limit and inadvertently extracts beam to NSRL. The limits are:

Table I: Beam Limits

Area	ASE Limit in an hour	OPM	Maximum achieved
NSRL	6×10^{14} GeV-nuc.	2.5.3.1	
Booster	1.1×10^{18} GeV-nuc.	2.5	
Linac	1.1×10^{18} GeV-nuc.	2.5	
Booster			1.1×10^{17} GeV-nuc. ²

During past high intensity proton operations the Booster operated at a maximum of 10% of the present ASE. There is more than a factor of 30 between the hourly limit for the Booster and the hourly limit for NSRL.

The fault studies determined for specific loss locations what beam intensity would make the chipmunk interlock the beam off. At lower beam intensities the chipmunk would provide an alarm in MCR for the operators to respond to. Table II below provides details of beam intensity to cause a chipmunk interlock. For many of the beam fault locations the beam intensity is more than an order of magnitude lower than the Booster maximum. Even for clean transport to the beam dump the intrinsic losses cause the upstream chipmunk to interlock. This value, 6.5×10^{17} GeV-nucleons will be used as the upper limit for beam faults in the downstream section. A section of the beam transport between the PS building and the target room may allow maximum beam faults to occur. Additional fault studies would need to be conducted to determine if this is possible. Instead it will be assumed that is the case and see if the dose at the berm fence is sufficiently low that we can rely on administrative processes to prevent exceeding the 20 mrem dose in a fault.

Table II: Beam Intensity for Chipmunk Interlocks

Loss point	Chipmunk Monitor	Beam intensity for interlock GeV-nuc per hour
RD1/RD2	132	1.4×10^{16}
Beam pipe near penetrations	132	2.88×10^{16}
Clean transport to beam dump	132	6.5×10^{17}
Thick target in target room	131	5.8×10^{15}
Gate valve	131	6.5×10^{16}
Clean transport into beam dump	131	7.2×10^{16}

² Kip Gardner, Booster Beam Intensity Data, Nov. 1, 2010; <http://www.cad.bnl.gov/esfd/RSC/Memos/BeamIntensityData.pdf>

Beam Fault Dose on Berm Compared to a Fence

The Monte Carlo program MCNPX³ was used to model the NSRL berm and fence location. The cross sectional view of the NSRL berm shown in Figure 3 will be simplified to build a model in MCNPX. The berm is at least 4.8 meters thick on top. The earthen shield on the west has the user area, Building 958, and support building, Building 957. The slope of the earthen shield is shorter and steeper on west side. The thickness of earthen shield is thinnest, approximately 4.8 meters thick, approximately 4 meters down the west slope from the top. A simple model is to place the “vertical” axis at this location and extend the berm to the other side. This should provide an overestimation of the radiation at the fence.

The MCNPX geometry is shown in Figure 4. The tunnel is approximated with a 120cm radius tunnel with a steel target 3cm in radius and 100 cm long. A pencil beam of 3.0 GeV protons strikes the front of the target a $z=0$ cm in the center. The soil is assumed to have a density of 1.8 gm/cm^2 and a thickness of 360 cm (approx. 12 feet). A reduced soil thickness is used to reduce computation time and then will be scaled to the actual thickness. Importance factors were used to increase the proportion of time spent computing the radiation at the thicker layers of soil. The dose was evaluated at each 30 cm layer of soil and on the cylindrical surface, which as a radius of 15 meters. The geometry has a finite z range of $z=-200\text{cm}$ to $z=600$ cm. The dose surface 67 was integrated in strips one meter wide and eight meters long.

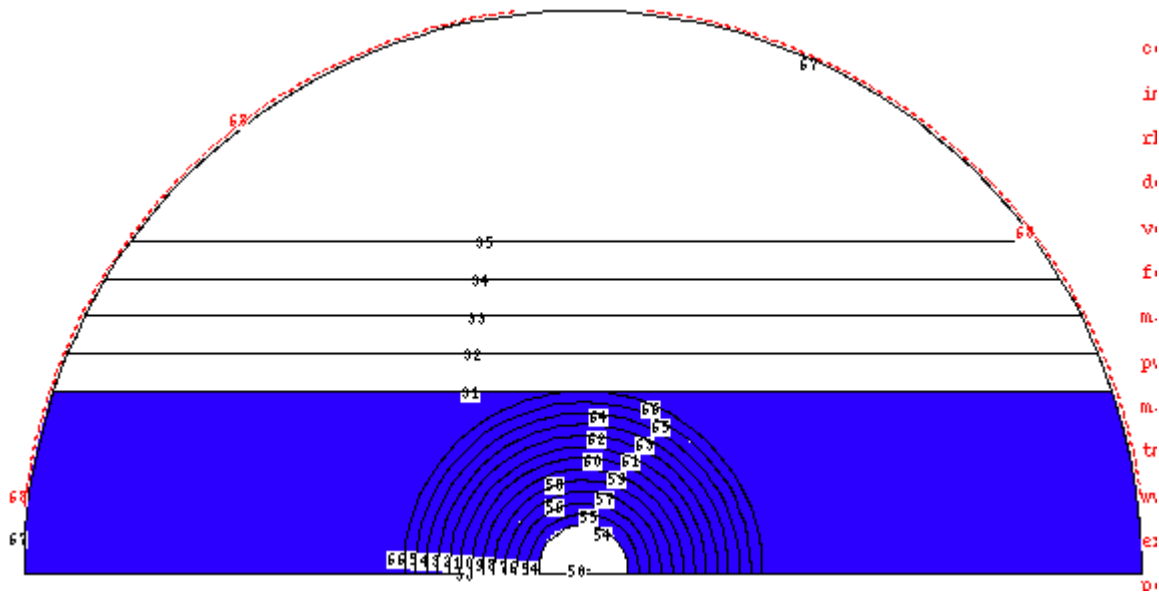


Figure 4: Model of the NSRL earthen shield in MCNPX.

The dose per proton is tabulated for strips near the fence line and above the berm in Table III. The statistics are poor for the two strips that would be just above ground level at the fence. The dose at the fence is at least 50 times lower than the dose directly over the source. Integration was done over a shorter surface (5 meters) and found to increase by 20% at 15 meters.

³ MCNPX reference

Table III: Dose Per Proton on the Cylindrical Surface 67 (15 meters from source)

Surface 67 location	Dose in rem/p	Ratio to vertical center	comment
0 to 100cm (vertical)	$1.26 \cdot 10^{-19}$	0.005	Poor statistics
100 to 200cm (vertical)	$4.51 \cdot 10^{-19}$	0.017	Poor statistics
200 to 300cm (vertical)	$8.5 \cdot 10^{-18}$	0.032	
300to 400cm (vertical)	$1.86 \cdot 10^{-18}$	0.069	
-250 to -150cm (horizontal)	$2.51 \cdot 10^{-17}$	0.93	
-150 to -50cm (horizontal)	$2.69 \cdot 10^{-17}$	1	
-50 to 50cm (horizontal)	$2.69 \cdot 10^{-17}$	1	

These numbers can be used to obtain the dose at the fence. The model was used to measure the dose as a function of depth in the soil. Figure 5 displays the dose along with a curve that approximates the data points with a simple $(1/r^2) \cdot \exp(-d/l)$ where l is the attenuation length. A value of 120 gm/cm^2 was used for the curve and is reasonable. The additional soil would reduce the numbers by a factor of 0.18. Assuming a height of 2-3 meters above ground at the fence a dose of 20 mrem would be reached after 21 minutes if the booster delivered the maximum beam it has ever operated with. The 20 mrem could be reached in 3.6 minutes if the only Booster operates at $6.5 \cdot 10^{17}$ GeV-nucleons per hour. The NSRL ASE would be violated in 10 seconds with this beam rate.

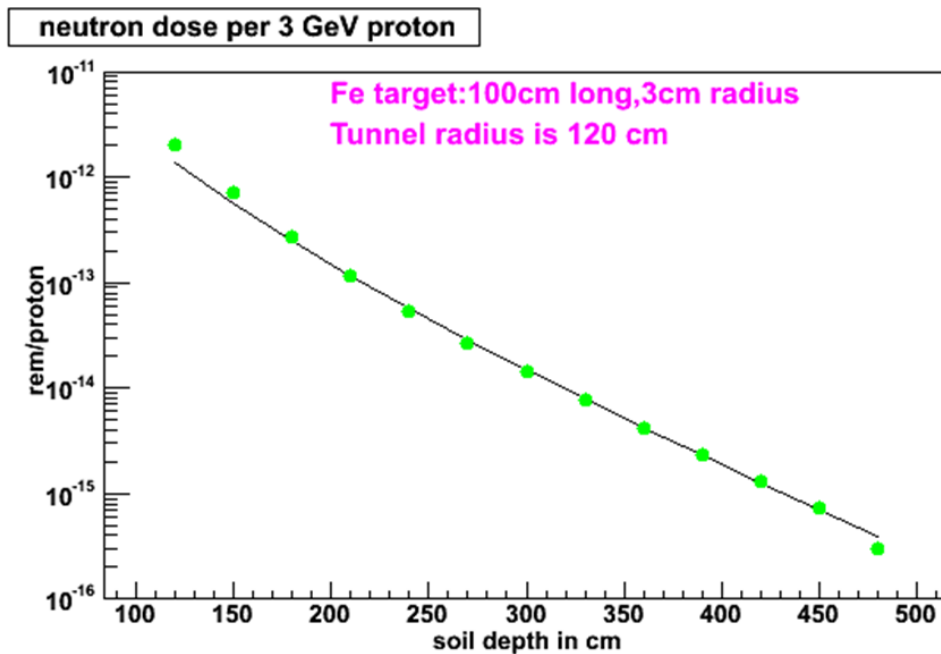


Figure 5: Dose per proton as a function of radius for the model. The solid line is an exponential with one over radius squared and the soil starts at a radius of 120cm.

The Power supply building has a second floor. A person standing near the wall to the berm could have an exposure which would be at a height of 20 feet above the ground. This would be at an angle of 63 degrees from the axis used in the model. To examine the shape of the dose curve with angle from the zenith simple simulations were conducted by throwing fixed energy neutrons

at a slab of soil 1.8 meter thick. The dose as a function of angle was calculated. The results for 200 MeV, 50 MeV and 10 MeV neutrons are displayed in Figure 6. The results from the simulation for NSRL given in Table III are displayed as black triangles. The data are described well by the simple curve form the fixed neutron data. The curve will be used to extrapolate the NSRL simulation to other angles from the zenith.

The dose rate on the second floor is estimated⁴ to be 1.55×10^{-18} rem/proton. In this region the upstream labyrinth chipmunk would be expected to limit the proton loss rate to 2.88×10^{16} . The 20 mrem dose limit would be reached in 27 minutes of the intensity. The chipmunk alarm would have been activated during this entire time. The chipmunk alarm threshold is a factor of 2.5 lower so if the beam loss rate is just below the alarm threshold it would take 68 minutes for the dose to reach 20 mrem on the second floor.

The user facility, Building 958, has only a single floor. However, work can be conducted on the building. A present there are scaffolds on the east side of the building for work to be conducted on the gutters. The workers could be 15 feet above the ground level and are 15 feet from the fence. Another possibility is for workers to be on the roof and be 25 feet above the ground and about 25 feet from the fence. The maximum beam intensity that does not trip the interlocks if NMON130 is absent is 6.5×10^{17} . The dose at the platform could reach 20 mrem in 54 seconds and on the roof in 43 seconds. The corresponding dose rates are 1300-1600 mrem/hr for this hypothetical fault.

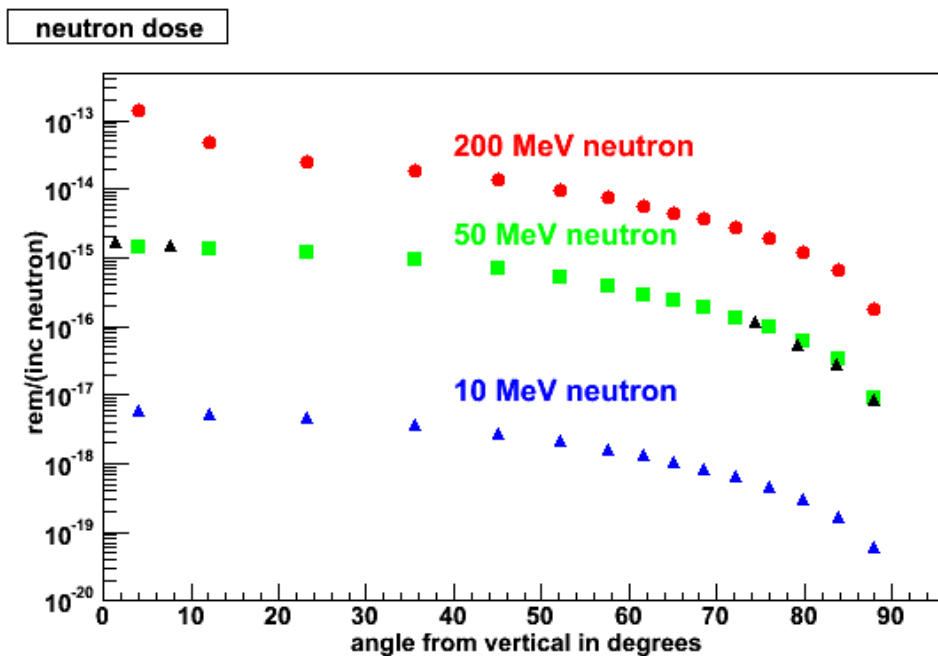


Figure 6: The neutron dose as a function of the neutron energy incident on a 1.8 meter slab of soil. The black triangles are the results of the earlier simulation for protons in the NSRL geometry.

⁴ The estimate includes a factor of 0.2 for the zenith angle and a factor of 1.61 to account for change in solid angle. Effectively the building is leaning in towards the source in the model coordinates.

Summary and Conclusions

Although it may be theoretically possible for these faults to happen it is very unlikely. It should not expect that the Booster could be able to operate at a beam performance level that it has never achieved. In addition it takes additional errors for the booster beam intended for the AGS to be sent to NSRL. In such a case the most likely fault is for the beam to crash in the upstream end or NSRL since NSRL typically operates at low energies. It should be concluded that it is not credible for such a large fault to occur.

It then becomes necessary to consider what is the maximum credible beam loss. It is suggested that the highest intensity achieved in the booster be used. In this case the time for a person to receive 20 mrem at various locations along the NSRL beam line is:

Table IV: Time to Achieve a 20 mrem Beam Fault Dose

Location	Time (minutes)	Beam Intensity
Second floor of Building 957	27	2.88×10^{16} GeV-n in an hour
Fence behind Building 958	21.2	1.1×10^{17} GeV-nuc.
On roof of Building 958	4.2	1.1×10^{17} GeV-nuc.

The risk of such faults is small. The NSRL ASE alarm would warn operators even if a chipmunk alarm did not. It is expected that the operators would respond to such an alarm in a few minutes. It would appear that in the worst credible case a person outside the fence would not receive a dose above 20 mrem if NMON130 was removed from the berm. Work on the roof of Building 957 and 958 are conducted under work planning. The work planning should catch the issue of potential dose to elevated workers. If desired the present two labyrinth chipmunks could be moved closer to the beam line so that they become more sensitive to beam faults in the tunnel. Additional fault studies with protons could be conducted. Buildings and roofs could be posted as Controlled Areas.

It is recommended that the berm chipmunk be removed. (ATS-10/10/2013-NSRL-Beavis&Rusek) Oct. 30, 2013

The RSC should consider any other controls are desired. (ATS-10/30/2013-NSRL-Beavis&Rusek)

CC:

P. Cirnigliaro
T. Curcio
T. Blydenburgh
D. Passarello